The effect of the in-medium Θ^+ pentaquark on the kaon optical potential

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The kaon nuclear optical potential is studied including the effect of the Θ^+ pentaquark. The one-nucleon contribution is obtained using an extension of the Jülich meson-exchange potential as bare kaon-nucleon interaction. Significant differences between a fully self-consistent calculation and the usually employed low-density $T\rho$ approach are observed. The influence of the one-nucleon absorption process, $KN \to \Theta^+$, on the kaon optical potential is negligible due to the small width of the pentaquark. In contrast, the two-nucleon mechanism, $KNN \to \Theta^+ N$, estimated from the coupling of the pentaquark to a two-meson cloud, provides the required amount of additional kaon absorption to reconcile with data the systematically low K^+-nucleus reaction cross sections found by the theoretical models.

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I. INTRODUCTION

The study of pentaquarks has become a matter of recent interest since the discovery by the LEPS collaboration at SPring-8/Osaka [1] of the exotic Θ^+ with strangeness $S = +1$, which has been confirmed by several other collaborations [2, 3, 4, 5, 6, 7]. The possibility of the existence of a narrow baryon resonance of mass 1.53 GeV, width of 15 MeV and quantum numbers $S = +1$, $I = 0$ and $J^P = 1/2^+$, was previously predicted by the chiral quark-soliton model of Diakonov et al. [8]. Actually, the position (1.54 GeV) and width (< 20 MeV) extracted from the experiments are compatible with the theoretical prediction. However, Nussinov [9], Arndt [10] and Gibbs [11] pointed out that widths larger than a few MeV were excluded since otherwise the Θ^+ would have been visible in the K^+N and K^+d data. Similar results were obtained when comparing the available data on total KN cross sections in the $I = 0$ and $I = 1$ channels with the predictions of the Jülich meson-exchange model for the KN interaction [12, 13], extended to incorporate a Θ^+-like resonance structure [14]. In a recent paper, this extended Jülich model has also been used to determine the width of the Θ^+ resonance through the analysis of the reaction $K^+d \to K^0pp$ [15].

Furthermore, the discovery of the Θ^+ pentaquark with positive strangeness opens the exciting possibility of producing exotic Θ^+ hypernuclei. Several authors have proposed that the Θ^+ would develop in the nuclear medium an attractive optical potential, the size of which might range, depending of the mechanism, from a few MeV to a few hundreds of MeV [16, 17, 18, 19, 20]. Therefore, understanding the in-medium properties of the Θ^+ pentaquark and its influence on the KN interaction in dense matter and, hence, on the kaon optical potential is something that deserves being investigated.

The medium properties of kaons have received a lot of attention over the last years [21, 22, 23, 24, 25, 26, 27, 28, 29] due to the fact that kaons are not only considered the best probes to study the dense and hot nuclear matter formed in heavy-ion collisions, but also because they probe partial restoration of the chiral symmetry in dense matter. The KN interaction has been believed to be smooth since no baryonic resonance with positive strangeness was allowed to exist and, therefore, the single-particle potential of kaons has usually been approximated by the $T\rho$ approximation or low-density theorem with a repulsion of around 30 MeV for normal nuclear matter density [26, 27]. Recently, a self-consistent calculation has been performed [29] showing a mass shift of 36 MeV at normal nuclear matter density. All the theoretical models of the kaon optical potential based on the $T\rho$ approximation failed systematically in reproducing K^+-nucleus total and reaction cross sections [30, 31, 32, 33, 34, 35, 36, 37], underestimating the data by about 10-15%. Although several mechanisms where explored, such as swelling of the nucleon, meson exchange currents, or a smaller

mass for the exchanged vector meson [38, 39, 40, 41], there is at present no satisfactory solution to this problem. However, a recent work obtained substantially improved fits to the data by incorporating the absorption of K^+ by nucleon pairs [42].

One of the aims of the present work is to revise the validity of the $T\rho$ approximation to the kaon optical potential, by performing fully self-consistent calculations using a medium modified KN effective interaction. In addition, we also investigate the changes on the kaon optical potential induced by the presence of the Θ^+ pentaquark in a dense medium. For this purpose, we start from an extension of the Jülich meson-exchange model for the KN interaction, which includes the Θ^+ pentaquark [14] as an additional pole term. From the two models explored in Ref. [14] giving, respectively, pentaquark widths of 20 MeV and 5 MeV, we only consider the latter one since it is closer to the upper limit of various recent quantitative analysis [10, 11, 15, 43]. We will see that the mechanism $KN \to \Theta^+$ gives a negligible contribution to the kaon optical potential due to the small coupling of the pentaquark to KN states. However, the pentaquark can also influence the kaon optical potential through the two-body mechanism $KNN \to \Theta^+ N$, as discussed in Ref. [42]. In the present work we perform a microscopic calculation of this mechanism taking the model of Ref. [44] for the coupling of the Θ^+ to a $K\pi$ cloud and allowing the pion to couple to particle-hole and Delta-hole excitations. We will see that the effect of this new channel on the kaon optical potential is appreciable, enhancing the calculated K^+ nuclear reaction cross sections enough to bring them in close agreement with the experimental data.

II. THE KAON OPTICAL POTENTIAL

In order to obtain the single-particle potential of a K meson embedded in infinite symmetric nuclear matter, we require the knowledge of the in-medium KN interaction, which will be described by a G-matrix. The medium effects incorporated in this G-matrix include the Pauli blocking on the nucleonic intermediate states as well as the self-consistent dressing of the K meson and nucleon.

The KN interaction in the nuclear medium is obtained taking, as bare interaction V, an extension of the meson-exchange Jülich interaction for KN scattering [12, 13] which incorporates the Θ^+ pentaquark as a polar term [14]. The values of the bare pentaquark mass, $M^0_{\Theta^+} = 1545$ MeV, and the bare coupling constant to KN states, $g^0_{KN\Theta^+}/\sqrt{4\pi} = 0.03$, were chosen to reproduce the observed physical mass and a width of 5 MeV after solving, in free space, the Lippmann-Schwinger equation which couples the pentaquark term with the other non-polar terms of the KN potential.

In a schematic notation, the G-matrix reads

$$\begin{aligned}\langle KN \mid G(\Omega) \mid KN\rangle \quad &= \langle KN \mid V(\sqrt{s}) \mid KN\rangle \\ &+\langle KN \mid V(\sqrt{s}) \mid KN\rangle \frac{Q_{KN}}{\Omega - E_K - E_N + i\eta}\langle KN \mid G(\Omega) \mid KN\rangle \ ,\end{aligned} \tag{1}$$

where Ω is the so-called starting energy, given in the lab frame, and $\sqrt{s}$ is the invariant center-of-mass energy. In Eq. (1), K and N represent, respectively, the kaon and the nucleon, together with their corresponding quantum numbers, such as coupled spin and isospin, and linear momentum. The function Q_{KN} stands for the Pauli operator preventing scattering to occupied nucleon states below the Fermi momentum. Eq. (1) is solved in a partial wave representation, including angular momentum channels up to $J = 4$. A detailed description of the method can be found in Refs. [45, 46].

This G-matrix equation has to be considered together with a prescription for the single-particle energies of kaons and nucleons in the intermediate states. In the case of kaons, their single-particle energy is obtained self-consistently from

$$E_K(\vec{q};\rho) = \sqrt{m_K^2 + \vec{q}\,^2} + \mathrm{Re}\, U_K(E_K, \vec{q};\rho) \ , \tag{2}$$

where U_K is the complex single-particle potential which, in the Brueckner-Hartree-Fock approach, is given by

$$U_K(E_K, \vec{q};\rho) = \sum_{N\le F} \langle KN \mid G_{KN\to KN}(\Omega = E_N + E_K) \mid KN\rangle \ , \tag{3}$$

where the summation over nucleon states extends up to the nucleon Fermi momentum. The kaon optical potential relates to the kaon self-energy through $\Pi_K = 2E_K U_K$. The nucleon single-particle energies are taken from a relativistic $\sigma - \omega$ model with density-dependent scalar and vector coupling constants [47]. In this model the attraction felt by the zero momentum nucleons in nuclear matter at saturation density is of the order of -80 MeV.

The kaon optical potential of Eq. (3) must be determined self-consistently, since the KN effective interaction (G-matrix) depends on the K single-particle energy Eq. (2), which in turn depends on the K potential. We proceed as

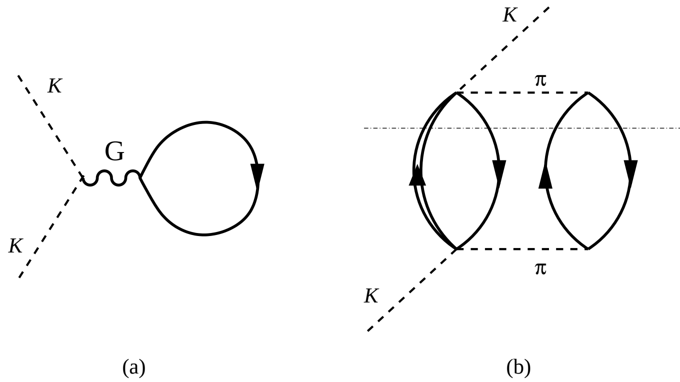

FIG. 1: One-nucleon (a) and two-nucleon (b) contributions to the kaon self-energy.

in Refs. [45, 46], where self-consistency for the optical potential of the antikaon was demanded at the quasi-particle energy, a simplification that proved to be sufficiently good.

In a diagrammatic notation, the kaon optical potential obtained from Eq. (3) is depicted schematically in Fig. 1(a), with the wiggled line representing the G-matrix and the solid one a nucleon hole. This diagram implicitly contains, in the $J = 1/2$, $L = 1$ KN channel, the effect of the pentaquark on the kaon optical potential coming from the process $KN \to \Theta^+$, which is driven by the small value of the $KN\Theta^+$ coupling constant.

The kaon self-energy may also receive contributions from the two-nucleon process, $KNN \to \Theta^+ N$, which might be thought as coming from the mechanism depicted diagrammatically in Fig. 1(b), where a particle-hole (ph) or Delta-hole (Δh) excitation absorbs the virtual pion emitted at the $\Theta^+ K\pi N$ vertex. This coupling was evaluated in a study of the meson cloud effects on the baryon antidecuplet binding in free space [44] and latter applied in a calculation of the Θ^+ self-energy in nuclear matter [17]. The contribution of diagram 1(b) to the kaon self-energy is given by

$$\Pi_K^{2N}(q^0, \vec{q}; \rho) = i \int \frac{d^4k}{(2\pi)^4} \left[D_\pi^{(0)}(k)\right]^2 \Pi_\pi(k;\rho) \tilde{U}_\Theta(q,k;\rho) \ , \tag{4}$$

where $D_\pi^{(0)}(k)$ is the free pion propagator, $\Pi_\pi(k;\rho)$ stands for the $ph + \Delta h$ contribution to the pion self-energy and $\tilde{U}_\Theta(q,k;\rho)$ corresponds to the pentaquark-hole bubble including the $\Theta^+ K\pi N$ vertices, namely

$$\begin{aligned} \tilde{U}_\Theta(q,k;\rho) = & \ 9\, i \sum_{j=S,V} \int \frac{d^4p}{(2\pi)^4} \mid t^{(j)}(k,q,p) \mid^2 \\ & \left\{ \frac{1-n(\vec{p})}{p^0 - E_N(\vec{p}) + i\varepsilon} + \frac{n(\vec{p})}{p^0 - E_N(\vec{p}) - i\varepsilon} \right\} \left\{ \frac{1}{p^0 + q^0 - k^0 - E_\Theta(\vec{p} + \vec{q} - \vec{k}\,) + i\varepsilon} \right\} \\ \simeq & \ -9 \sum_{j=S,V} \mid t^{(j)}(k,q) \mid^2 U_\Theta(q-k;\rho) \ , \end{aligned} \tag{5}$$

where the isospin factor 9 results from the sum over the processes $K^+p \to \Theta^+\pi^+$ and $K^+n \to \Theta^+\pi^0$, the quantity $U_\Theta(q-k;\rho)$ stands for the pentaquark-hole Lindhard function, and the scalar and vector couplings are given by

$$\begin{aligned} \mid t^{(S)}(k,q) \mid^2 &= -\left(\frac{\tilde{g}}{2f}\right)^2 \left[1 + \frac{M_\Theta}{E_\Theta(\vec{q} - \vec{k}\,)}\right] \\ \mid t^{(V)}(k,q) \mid^2 &= -\left(\frac{g}{4f^2}\right)^2 \Bigg[\left(1 + \frac{M_\Theta}{E_\Theta(\vec{q}-\vec{k}\,)}\right)(k^0+q^0)^2 + \frac{2}{E_\Theta(\vec{q}-\vec{k}\,)}(\vec{k}^2 - \vec{q}^{\,2})(k^0+q^0) + \\ & \qquad \left(1 - \frac{M_\Theta}{E_\Theta(\vec{q}-\vec{k}\,)}\right)(\vec{k}+\vec{q}\,)^2\Bigg] \left|\frac{m_{K^*}^2}{(q-k)^2 - m_{K^*}^2}\right|^2 \ , \end{aligned} \tag{6}$$

with $f = 93$ MeV the pion decay constant, $g = 0.32$ and $\tilde{g} = 1.9$ [44]. Note that in the last equality of Eq. (5) we have ignored the dependence of the vertices in the nucleon momentum $\vec{p}$ since it is small in the Fermi sea.

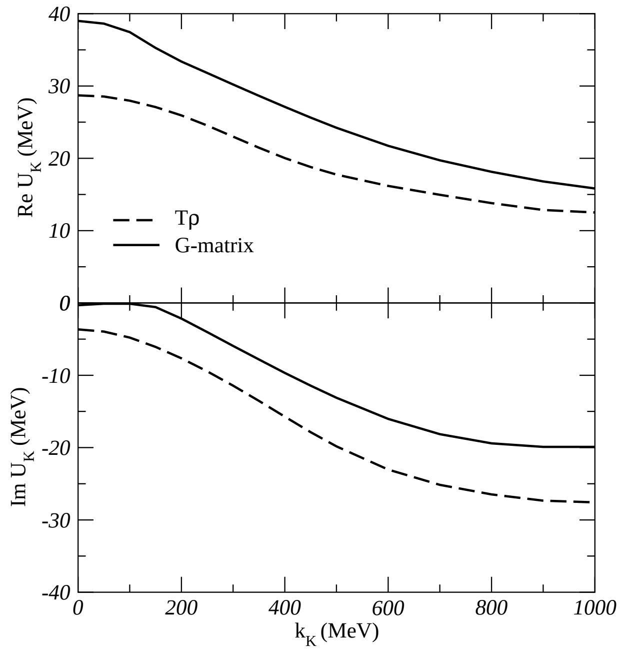

FIG. 2: Real and imaginary parts of the kaon optical potential as functions of the momentum of the kaon at normal nuclear matter density for the $T\rho$ approximation (dashed lines) and the G-matrix calculation (solid lines).

For practical reasons, the diagram of Fig. 1(b) is evaluated replacing, in the integrand of Eq. (4), the quantity $\left[D_\pi^{(0)}(k)\right]^2 \Pi_\pi(k;\rho)$ by the full in-medium pion propagator, $D_\pi(k;\rho)$, which is dressed with a pion self-energy containing the coupling to particle-hole and Δ-hole excitations and modified by short range correlations effects via a Landau-Migdal parameter $g' = 0.6$ [48, 49, 50]. Since we are only interested in the imaginary part of the kaon self-energy and we keep below the pion production region, we do not need to subtract the lowest order pion production diagram which is implicitly implemented by the above mentioned replacement.

III. RESULTS

We start this section with an analysis of the kaon optical potential when the Θ^+ pentaquark is not present. In Fig. 2 we display the real and imaginary parts of the kaon potential as a function of the momentum at normal nuclear matter density, $\rho_0 = 0.17$ fm^{-1}. The solid lines stand for the self-consistent G-matrix calculation and the dashed lines show the results of the low-density approximation, resulting from replacing G by the free amplitude T in Eq. (3). Our $T\rho$ approach ignores the medium corrections on the KN effective interaction as well as the in-medium single particle potentials of the K and N, but considers the effects of Fermi motion. This is the reason for having a non vanishing value of the imaginary part of the $T\rho$ optical potential at zero kaon momentum. For a momentum of 500 MeV/c, the size of the imaginary part of the optical potential would be reduced by 5% if Fermi motion was disregarded. We also observe that, at zero momentum, the real part of the kaon potential in the $T\rho$ approximation is about 10 MeV less repulsive than in the case of the self-consistent approach which gives an overall repulsive potential of 39 MeV. It is interesting to note that in Ref. [29], where self-consistency was also imposed, a similar repulsion of 10 MeV with respect to the calculation using the free space amplitudes was found. Our value of 29 MeV for the kaon optical potential at zero momentum in the $T\rho$ approximation is a few MeV larger than that in Ref. [29] but very similar to that obtained with other chiral models [26, 27]. The imaginary part grows slowly with increasing momentum and at 400 MeV it has a value of -9 MeV, which would correspond to a width of 18 MeV, slightly larger again than that found in Ref. [29].

The results in Fig. 2 demonstrate that medium corrections are relevant even for the weak, featureless and smoothly energy-dependent KN amplitude. These effects are clearly manifest in the optical potential of the kaon and, therefore, have an influence on its in-medium properties.

We next study the manifestation of the presence of the Θ^+ pentaquark on the kaon optical potential. For this purpose, we first show in Fig. 3 the real and imaginary parts of the G-matrix for $L = 1$, $J = 1/2$ and $I = 0$ as

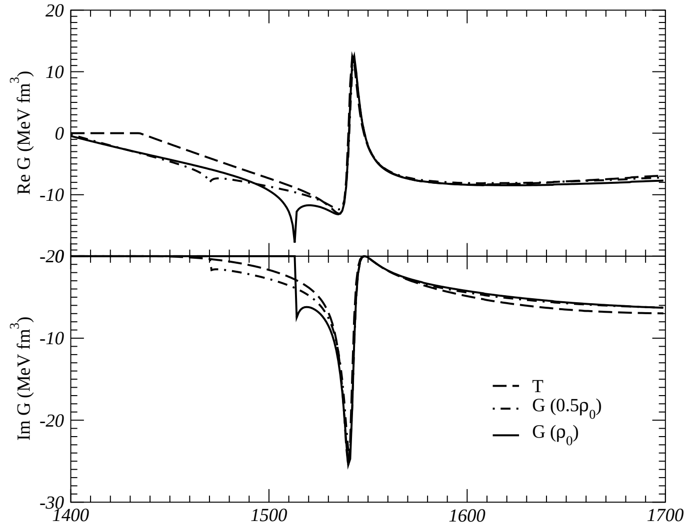

FIG. 3: Real and imaginary parts of the G-matrix for $L = 1$, $J = 1/2$ and $I = 0$ as functions of the center-of-mass energy at a total momentum $|\vec{k}_K + \vec{k}_N| = 0$ for different densities considering a Θ^+ pentaquark with a width of 5 MeV.

a function of the center-of-mass energy for a total momentum $|\vec{k}_K + \vec{k}_N| = 0$, including a Θ^+ pentaquark with a width of 5 MeV in free space. The cases shown correspond to the free T-matrix amplitude (dashed lines), the in-medium G-matrix amplitude for 0.5 ρ_0 (dot-dashed lines) and ρ_0 (solid lines). We observe that the structure in the KN amplitude associated to the presence of the Θ^+ pentaquark barely changes its position and the width is hardly altered, except for the fact that it appears distorted by the in-medium modification of the KN threshold, which at normal nuclear matter density lies around 1520 MeV. In spite of the fact that the pentaquark is included explicitly as an additional polar term in the KN Jülich potential, one would not have anticipated this insensitivity to medium effects. We recall, first, that the physical position and width of the pentaquark, as seen in the free space amplitude shown in Fig. 3, are generated after the multiple iterations involved in the T-matrix equation. Secondly, if only the polar pentaquark term of the potential was iterated, the width would be given from

$$\Gamma = \frac{1}{\pi}\left(\frac{g^0_{KN\Theta^+}}{2m_N}\right)^2 \frac{m_N}{M_{\Theta^+}} q^3_{\rm on} \ , \tag{7}$$

and, taking the bare value for the coupling constant quoted above, one would obtain a value around 1.2 MeV, four times narrower than it ends up being when the complete potential is iterated in the Lippmann-Schwinger equation. In other words, in the extended Jülich model the width of the pentaquark is largely generated from the interferences between the polar and non-polar terms of the interaction. Since medium effects affect the size of these interferences (by modifying the phase space of intermediate KN states) one in principle would have expected larger in-medium corrections on the width of the pentaquark. Changes are drastic only for higher densities, where the in-medium KN threshold moves to energies higher than the position of the pentaquark, and the width obviously drops to zero.

Once we have obtained the in-medium KN amplitude including the effect of the Θ^+ pentaquark, we can proceed to examine the consequences of the existence of this pentaquark on the optical potential of kaons. In Fig. 4 the real and imaginary parts of the kaon optical potential are displayed as functions of the momentum for 0.5 ρ_0 (left panels) and ρ_0 (right panels). The self-consistent kaon potential without Θ^+ is shown by the dashed lines. The solid line represents the optical potential when the $KN \to \Theta^+$ mechanism is included. Although some changes are seen for momentum values larger than 300 MeV/c, the effect is practically negligible and this is tied to the small value of the $KN\Theta^+$ coupling constant.

We next present in Fig. 5 the contribution to the imaginary part of the the kaon optical potential coming from the $2N$ mechanism as a function of the nuclear density for a kaon momentum of 500 MeV/c. These results exhibit the expected ρ^2 dependence and have a significant size. At normal nuclear matter density, the contribution of the two-nucleon mechanism to the imaginary part of the kaon optical potential for a momentum of 500 MeV/c is almost half of that corresponding to one-nucleon reactions.

Following Ref. [51], we calculate absorption and reaction cross sections, $\sigma_{\rm abs}$ and σ_R, from the expression:

$$\sigma = \int d^2b \left[1 - \exp\left(-\int_{-\infty}^{\infty} -\frac{1}{q}{\rm Im}\,\Pi(q;\rho(\vec{b},z))dz\right)\right] \ , \tag{8}$$

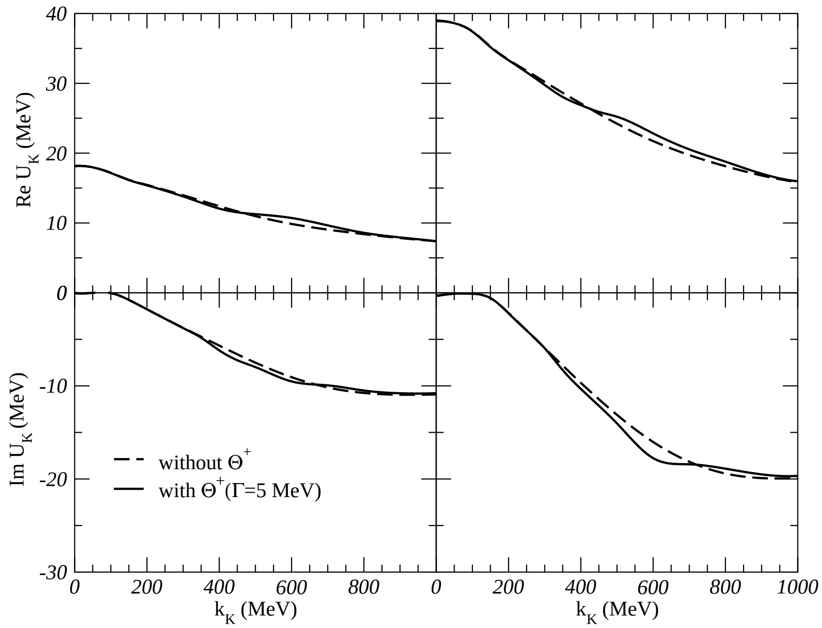

FIG. 4: Real and imaginary parts of the kaon optical potential as functions of the momentum of the kaon for 0.5 ρ_0 (left panels) and ρ_0 (right panels), without Θ^+ (dashed lines) and including a Θ^+ resonance with a width of 5 MeV (solid lines).

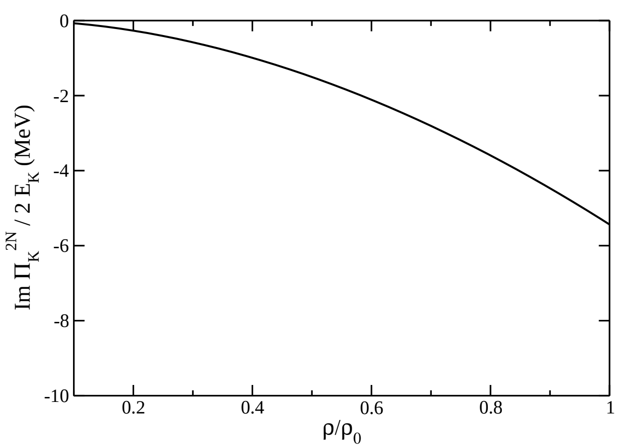

FIG. 5: Imaginary part of the $2N$ contribution to the kaon optical potential as function of the density for a kaon momentum of 500 MeV/c.

using, respectively, the two-nucleon component of the kaon self-energy, Π_K^{2N}, or the total self-energy containing, in addition, the contribution of the one-nucleon processes. The cross section is thus obtained as the integral over the impact parameter of one minus the probability that the kaon crosses the nucleus without reacting (in case of σ_R) or without being absorbed (in case of $\sigma_{\rm abs}$). We note that, in the latter case, we do not remove from the flux the kaons that undergo quasielastic collisions since they can still be absorbed. Although the eikonal formalism assumes the quasielastic scattered kaons to keep moving in the forward direction, it is still a reasonably good approximation for inclusive observables as is the case of the cross sections calculated here. An upper bound of the effect of distortions on the absorption cross sections would be obtained from the expression:

$$\sigma_{\rm abs} = \int d^2b\, dz \exp\left[- \int_{-\infty}^{z} -\frac{1}{q} {\rm Im}\,\Pi(q;\rho(\vec{b},z'))dz' \right] (-)\frac{1}{q}{\rm Im}\,\Pi_{\rm abs}(q;\rho(\vec{b},z)) \ , \tag{9}$$

with Π being the total self-energy, which removes from the flux the kaons that have suffered any type of reaction before

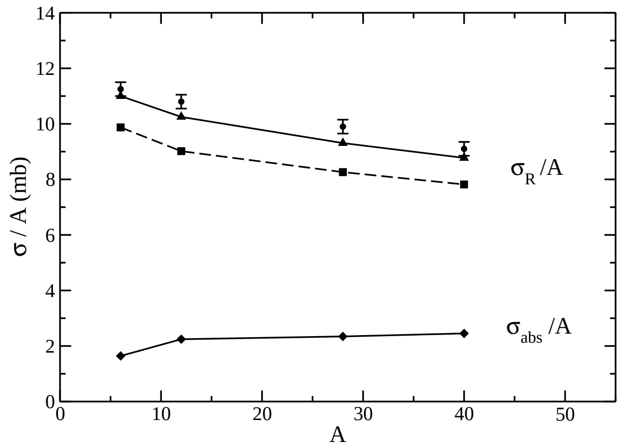

FIG. 6: Absorption and reaction cross sections per nucleon for a kaon laboratory momentum of 488 MeV/c, from a $G\rho$ kaon optical potential (dashed line) and including, in addition, the 2N-absorption mechanism (solid line). Data for the reaction cross sections are taken from the analysis of [37].

reaching the absorption point z. This would be more in line with the Distorted Wave Impulse Approximation-like expression used in Ref. [42].

In Fig. 6 the calculated cross sections per nucleon in ^{6}Li, ^{12}C, ^{28}Si and ^{40}Ca using Eq. (8) are compared to experimental data. The dashed line is obtained with the $G\rho$ kaon optical potential of Eq. (3) and underestimates the data by about 15%. By inspecting Fig. 2 one would then expect the $T\rho$ model to properly describe or even overestimate the data, in apparent contradiction to the previous theoretical calculations which underestimate data by 10-15%. We note, however, that we are not using here the experimental amplitudes but those obtained with the Jülich model I of Ref. [12]. This model reproduces the threshold scattering observables, but the $I = 0$ and $I = 1$ cross sections at 500 MeV/c and higher are slightly larger than the experimental ones. The absorption cross sections per nucleon obtained from the $2N$ mechanism are about 2-3 mb, right below the upper bound of 3.5 mb established in Ref. [42] from a phenomenological analysis including $2N$ absorptive effects. The use of the alternative Eq. (9) produces lower values of the absorption cross sections, slightly below 2 mb. The reaction cross sections per nucleon obtained with the complete imaginary part of the kaon self-energy, including both the one- and two-nucleon processes, lie very close to the experimental data. Clearly, our model for the two-nucleon kaon absorption mechanism provides the required strength to bring the reaction cross sections in agreement with experiment, thereby giving a possible answer to a long-standing anomaly in the physics of kaons in nuclei.

We would also like to comment on the possibility that the in-medium pentaquark develops, through its interaction with nucleons, an attractive potential, which might range from a few MeV to an astonishing value of a few hundreds of MeV [16, 17, 18, 19, 20]. This attraction can be thought as coming from a strong coupling of the pentaquark to K^*N states. The Jülich model does not incorporate such a coupling and, as a consequence, it is not included in the corresponding one-nucleon contribution to the kaon optical potential displayed in Fig. 4. Actually, the coupling to K^*N states would have moved to smaller momentum values the range of influence of the pentaquark on the kaon self-energy, but its effect would remain negligible since it is driven by the small value of the Θ^+KN coupling constant. The two-nucleon mechanism partly includes the Θ^+K^*N coupling since the two-meson cloud in the $\Theta^+K\pi N$ vertex reconstructs a K^* meson, as discussed in Ref. [44] and illustrated by the presence of the vector-meson form factor in Eq. (6). In addition, and for consistency, we should dress the pentaquark in diagram 1(b) by adding an attractive potential to its energy. However, a similar binding should be considered for the nucleon and both effects largely compensate each other. In any case, the possible induced error certainly lies within the uncertainties of our model for the two-nucleon absorption mechanism, which we estimate to be within 30%.

IV. CONCLUSIONS

We have performed a microscopic self-consistent calculation of the single-particle potential of a K meson embedded in symmetric nuclear matter, using the meson-exchange Jülich KN interaction. We have investigated the differences between the full self-consistent calculation of the K optical potential and the $T\rho$ approximation. The medium modifications on the KN amplitude affect the value of the K optical potential. While the $T\rho$ approach gives a repulsive potential of 29 MeV at zero momentum, the full self-consistent calculation increases the repulsion up to 39

MeV, in line with what is observed in the work of Ref. [29], where self-consistency was also implemented.

We have also studied the effect on the kaon optical potential of the existence of the Θ^+ pentaquark in a dense medium. We first obtain an in-medium KN effective interaction starting from an extension of the meson-exchange potential of the Jülich group, which includes the Θ^+ resonance. Neither the position nor the width of the pentaquark change appreciably in the medium, as long as there is available KN phase space to decay into. We note, however, that the pentaquark would have developed a strong binding in the medium if the coupling to K^*N states had been explicitly included in the Jülich model.

The effect of the Θ^+ on the kaon optical potential coming from the one-nucleon process $K \to \Theta^+ N$ is negligible due to a very small value of the $\Theta^+ KN$ coupling constant. In contrast, the two-nucleon absorption mechanism, $KNN \to \Theta^+ N$, contributes significantly to the imaginary part of the kaon optical potential, being almost half of the $G\rho$ value at normal nuclear matter density.

The new two-nucleon mechanism calculated in this work produces K^+ nuclear absorption cross sections per nucleon of about 2-3 mb. In addition, the reaction cross sections per nucleon are increased by 10-15% with respect to the $G\rho$ values, and turn out to be practically in agreement with the experimental data, thereby confirming the expectations of a recent phenomenological analysis [42].

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